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A COMPARISON OF EXPLOSIVES IN A CONICAL SHOCK TUBE

By
M. M. Swisdak, Jr.

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NOL

UNITED STATES NAVAL ORDNANCE LABORATORY, WHITE OAK, MARYLAND

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ATTENTION

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ABSTRACT: Experiments are being performed to determine whether or not the 180-foot conical shock tube facility located at the Naval Ordnance Laboratory can be used to determine free-air equivalent weights for several test explosives. The explosives tested were H-6, TNT, pentolite, and TNETB.

The rankings of explosives as determined in the CST agree with the rankings in free air.

Numerical values of equivalent weights vary with pressure, but even so the values obtained in the CST do not reproduce the single number usually cited for equivalent weights determined in free air using conventional methods. The variations are believed to be real and presently are thought as likely to represent an uncertainty in the conventional concept of equivalent weight just as much as a fundamental limitation of the conical shock tube.

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A COMPARISON OF EXPLOSIVES IN A CONICAL SHOCK TUBE

This report presents the results of a study to determine the feasibility of using the Naval Ordnance Laboratory 180-foot conical shock tube (CST) to make comparisons of the airblast performance of explosives.

This work was done under task number ORD 332-20(4)/092-1/UF20-354-310.

The identification of commercial materials implies neither endorsement nor criticism by the U. S. Naval Ordnance Laboratory.

E. F. SCHREITER
Captain, USN
Commander

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By direction

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1. INTRODUCTION

In recent years, many new explosive compositions have been developed and are being considered for ordnance applications. In order to choose the best explosive composition for a particular application, these new explosives need to be ranked according to their effectiveness and quantitatively evaluated if possible. The airblast parameters of interest here are peak overpressure and positive impulse.

Rankings of many new explosives based upon thermochemical calculations have not been possible, because the high percentages of aluminum and/or inert materials they contain have precluded making such rankings. In addition, problems in free-field testing such as repositioning of gages, criticality of charge alignment with gage arrays, and the requirements for relatively large quantities of explosives have always made such tests difficult. Because small quantities of explosive in a conical shock tube can be used to simulate the effects of much larger charges in free air, it was felt that it would be a great saving of both time and money if the explosive-driven conical shock tube (CST) facility located at the Naval Ordnance Laboratory could be used. A firing program using four explosives: TNT, H-6, pentolite, and TNETB was conducted at this facility to determine whether or not the CST could be used for the purpose of making explosive comparisons.

2. EXPERIMENTAL PROGRAM

All firings were conducted at the NOL conical shock tube facility. This facility has been previously described.[1] Measurements were made at seven gage stations located along the shock tube. The positions of these stations are listed in Table 1.

a. <u>Instrumentation</u>: Two types of transducers were used in these tests -- a piezoelectric gage manufactured by Atlantic Research Corporation (Model LC-70, having a lead zirconate-titanate sensing element) and a variable reluctance (FM) gage manufactured by Consolidated Controls Corporation . Both types were flush mounted in the wall of the CST, i.e., they were used to measure side-on pressures.

[1]References are on page 8.

The output from the piezoelectric gages was fed into signal conditioning amplifiers[2] and then to the recording apparatus via 400 feet of RG-58 coaxial cable. During the first portion of these tests, the gage signals were displayed directly on Tektronix 502A oscilloscopes and recorded with Polaroid cameras. Later, an Ampex FR-1800L magnetic tape recorder was used to record the data which were reproduced later. The variable reluctance gage data were recorded directly upon magnetic tape and reproduced later through an FM discriminator.

b. Charges: Four explosive compositions were considered in these tests. They were pentolite, H-6, TNT, and TNETB. Pertinent information concerning the charges is given in Table 2. All the charges were cylindrical and initiated by a number 6 electric blasting cap inserted in a shallow hole at one end. The H-6 and TNT charges were boostered by the addition of a 1½" diameter x ½" long pentolite cylinder butted against them as shown in Figure 1.

After the charges were assembled and weighed, they were mounted on styrofoam trays weighing approximately .022 lb each. The charge/tray assembly was then inserted into the firing chamber of the CST. The purpose of the styrofoam tray was to position the charge on the axis of the firing chamber.

c. CST Nitrogen Atmosphere: For one series of pentolite shots a nitrogen atmosphere was substituted for the air normally present in the shock tube. This was accomplished by first evacuating the CST to a simulated altitude of 100 kft (an atmospheric pressure of 8.1 mm of mercury), then bleeding in nitrogen gas until a pressure slightly greater than ambient was obtained. The tube was then allowed to equalize its pressure with the outside atmosphere and was sealed off. Nitrogen gas was used since it has been shown that when charges are fired in a nitrogen atmosphere, the effects of air afterburning are excluded.[3]

d. Analysis Procedures:

(1) Pressure-Time Curve Analysis: The two explosion effects considered in these comparisons were peak overpressure and positive impulse. Also measured in some cases was the time of arrival of the shock at a particular gage location.

Referring to Figure 2, peak pressure (P) is defined as the maximum overpressure in the shockwave. In this study it was measured directly, using gages calibrated to a relative pressure standard.[6] Positive impulse (I) is defined by the following equation:

$$I = \int_0^\tau P(t)dt, \qquad (1)$$

where P(t) is the shock overpressure as a function of time, t, and τ is the duration of the positive phase of the blast wave. Positive impulse data were obtained by mechanically integrating the pressure-time records.

Table 3 indicates what types of information were obtained for the various combinations of explosives, charge weights, and CST atmospheres.

(2) <u>The Concept of Equivalent Weight</u>: A standard method used to rank the effectiveness of the test explosives has been their equivalent weight. Equivalent weight is defined as "the ratio of the weight of an explosive used as a standard of comparison to the weight of the explosive under test that will produce equal positive impulses or equal peak pressures at the same distance."[4]

This report deals largely with equivalent weights based upon peak pressure, so a further discussion of this quantity will be given. The cube-root scaling law requires that:

$$EW = \left(\frac{\lambda_{test}}{\lambda_{standard}}\right)^3_{P=constant} \qquad (2)$$

where λ_{test} and $\lambda_{standard}$ are the scaled distances* for the test and standard explosives. Maserjian and Fisher[4] have described several methods of data analysis for calculating equivalent weights. In their report, curves are fitted to the scaled distance-pressure data for the two explosives. Next, the ratio of the scaled distances (at a particular pressure) is calculated; the cube of this ratio is the equivalent weight according to equation (2).

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* The scaled distance, λ, is the distance from the charge in feet, divided by the cube root of the charge weight in pounds.

It is important to note that unless the two pressure-distance curves are exactly parallel the equivalent weight will be a function of the pressure at which it is calculated. In this report, equivalent weights will be presented in two forms: 1) showing its functional dependence upon the pressure, and 2) as a single number, averaged over the pressure range of interest.

e. Results: Time of arrival, peak pressure, and positive impulse data are tabulated in Tables 4, 5, and 6. The data are presented as a function of scaled distance ($ft/lb^{1/3}$) along the shock tube. All scaling has been done using the actual charge weight, rather than the "amplified" charge weight. The "amplified" charge weight is the weight of an explosive charge, which if fired in free air would duplicate the pressure-distance data taken in the CST using a much smaller charge size.

All equivalent weights presented herein are relative to TNT data taken in the CST, unless otherwise noted.

3. ANALYSIS AND DISCUSSION

Mean values of the test variables are plotted as functions of scaled distance in Figures 3 to 10. In each case, the points are the mean values of the parameters, while the solid lines are least-square curves which minimize the sums of the squares of the deviations of the data points from the fitted curves. Usually two charge weights are involved; note that over the range of charge weights used in these tests cube-root scaling appears to hold.

All pressure-distance data were fitted with equations of the form:

$$P = A \lambda^{B} , \tag{3}$$

where P is overpressure in psi and λ is scaled distance in ($ft/lb^{1/3}$). A and B are coefficients determined by the fitting routine. Preliminary fits of the data were made with higher order polynomials, but within the scatter of the data, no significant improvement was found over the simpler form (eq. (3)). B was close to -2 in all cases (-2.03 to -2.29).

Time-of-arrival data were fitted using a cubic equation of the form:

$$\overline{TOA}/W^{1/3} = a_0 + a_1 \lambda + a_2 \lambda^2 + a_3 \lambda^3 , \tag{4}$$

where $\overline{TOA}/W^{1/3}$ is scaled time of arrival in msec/lb$^{1/3}$, λ is again scaled distance (ft/lb$^{1/3}$), and a_0, ..., a_3 are coefficients. The fitted values for all the curves used in this report are tabulated in Table 7.

Upon examining the pressure-distance curve obtained for pentolite in the CST (Fig. 8) one observes that the points obtained from the firings of the 0.374-lb charges appear to be low, relative to the remainder of the data. At present, no apparent reason can be found for these low values. If the 0.374-lb data are excluded and a new least-squares fit is made for the remaining points, we find that the slope (B) does not change appreciably (-2.075 vs. -2.070), but the constant (A) increases by 2% (9.01×10^5 vs. 8.81×10^5). When these new values are used to determine the equivalent weight for pentolite, we see that the average equivalent weight is raised by at least 5%.

Because of the excessive scatter in the positive impulse data, no attempt will be made either to present the data in graphical form, or to use it to determine equivalent weights.

Figure 11 gives the equivalent weights (relative to TNT) as a function of pressure for the various explosives fired in this program. The pressure range of interest in this report is 10-100 psi. The various equivalent weights averaged over this range are presented in Table 8. Previous studies[3,5] made in free air have yielded equivalent weights in the 2-50 psi range. To provide a more direct comparison, CST equivalent weights, averaged over comparable pressure ranges, and the free-air equivalent weights are presented in Table 8.

Figure 12 shows the equivalent weight of pentolite fired in a nitrogen atmosphere in the CST relative to pentolite fired in a normal atmosphere in the CST as a standard of comparison. At the higher pressures (nearer the explosive charge) the equivalent weight is approximately 1, falling gradually to 0.75 farther along the tube. Over the pressure range 10-100 psi the average equivalent weight was 0.93. Averaged over the pressure range of 10-30 psi, the equivalent weight was 0.81. Matle, et al[6] have reported an equivalent weight of 0.83 for

pentolite fired under similar conditions over the pressure range of 5-30 psi (using a nitrogen-filled balloon to surround the charge with gages in air). Based upon this it can be concluded that the afterburning contribution to the equivalent weight for pentolite is the same in the conical shock tube as it is in free air.

Using the conventional equivalent weight methods described in paragraph 2d, over the 10-100 psi range in the CST, neither the rankings nor the absolute values for the equivalent weights agree with the free-air results for 2-50 psi. Better agreement is obtained when the CST results are restricted to a more nearly comparable range. However, even over this more limited range, we see that the CST does not appear to exactly duplicate free-air results, although pressure-time curves (Fig. 13) appear to have a fast rise time and exponential decay similar to an idealized curve.

Some of the disagreement between the free-air results and the shock tube results is due to the practice in previous work of presenting equivalent weights as a single number, instead of the dual methods used in the present report. The functional dependence of equivalent weight on pressure is shown in Figure 11, and averaged equivalent weights are presented in Table 8.

A newly developed analysis method[7] based upon the "available energy" concept is currently being used to re-examine recent pressure-distance data to determine an equivalent weight based upon the available energy in the blast wave. The results of this examination will be reported in a forthcoming report.

4. CONCLUSIONS

The contribution of afterburning to the equivalent weight of pentolite is the same in the CST as it is in free air.

For the charge weights used in these tests, cube-root scaling appears to hold in the conical shock tube. The conical shock tube does not reproduce the single numbers for equivalent weights usually cited for free air results using conventional methods of calculation.

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TABLE 1 GAGE STATION LOCATIONS ALONG THE 180' CST

STATION	DISTANCE FROM THEORETICAL CONE APEX (FT)
	46.0
1	47.5
	49.0
	68.5
2	70.0
	71.5
	93.5
3	95.0
	96.5
	116.0
4	117.5
	119.0
	148.5
5	150.0
	151.5
	176.0
6	177.5
	179.0
	222.0
7	223.5

TABLE 2 EXPLOSIVE CHARGE DATA

EXPLOSIVE	COMPOSITION (BY WEIGHT)	LOADING	OXYGEN BALANCE PERCENT (%) ∇		SIZE (DIA X LENGTH) (INCHES)	AVG. WEIGHT (POUNDS)***
			TO CO_2	TO CO		
PENTOLITE	50/50 PETN/TNT	CAST	-42	- 5	1-1/2 X 6 1-1/2 X 3 1-1/2 X 3-1/2	0.692 0.294 0.374
H-6	47/31/22/5 RDX/TNT/Al/WAX	CAST	-66	-36	1-1/2 X 6-1/2* 1-1/2 X 3-1/2*	0.715 * 0.380 *
TNT	PURE	CAST	-74	-25	1-1/2 X 6-1/2* 1-1/2 X 3-1/2*	0.672 * 0.362 *
TNETB**	PURE	CAST	- 4.2	+20.8	1-1/2 X 6 1-1/2 X 3	0.606 0.303

* INCLUDING 1-1/2 X 1/2 PENTOLITE BOOSTER WEIGHING 0.055 POUNDS

** 2,2,2 TRINITROETHYL - 4,4,4 TRINITROBUTYRATE

*** VARIATION IN CHARGE WEIGHT $\leq$ 1.0%

∇ REFERENCE 6

TABLE 3 EXPERIMENTAL CONDITIONS STUDIED

EXPLOSIVE	WEIGHT (LBS)	PROPAGATING MEDIUM	DATA OBTAINED		
			PEAK PRESSURE	IMPULSE	TIME OF ARRIVAL
TNT	.672	AIR	√	√	
	.362	AIR	√	√	
H-6	.715	AIR	√	√	
	.380	AIR	√	√	
PENTOLITE	.692	AIR	√	√	√
	.294	AIR	√	√	√
	.374	AIR	√		
	.692	N_2	√	√	√
TNETB	.303	AIR	√	√	√
	.606	AIR	√	√	√

TABLE 4A TIME OF ARRIVAL RESULTS

TIME OF ARRIVAL DATA FOR PENTOLITE
(WEIGHT = .692 LB)

SHOT# \ λ	53.70	77.44	107.39	132.83	167.87	200.66	250.96
3044	4.81	10.75	21.81	33.46	52.19	72.34	102.92
3045	4.73	10.62	21.21	32.29	50.32	70.03	100.16
3046	4.69	10.55	21.06	31.98	49.83	69.35	99.22
3053	4.87	11.02	21.61	32.33	49.78	68.90	98.18
3057	4.75	10.83	21.29	31.99	49.39	68.45	97.72
3058	4.84	11.02	21.80	32.77	50.61	70.06	100.02
3062	4.96	11.57	23.35	35.28	53.95	73.77	103.79
3069	4.88	11.32	22.55	33.53	51.04	70.05	99.18
3070	4.80	11.13	22.11	33.45	51.58	69.97	100.14
3071	4.82	11.11	22.05	33.39	51.53	69.89	99.98
3072	4.71	10.84	21.31	32.34	50.25	68.48	98.48
3073	4.68	10.66	20.97	31.90	49.76	67.99	98.02
3093	4.94	11.03	21.80	33.38	51.78	70.90	-
3094	4.57	10.67	21.35	32.59	50.52	69.26	-
$\overline{TOA}$	4.79	10.94	21.73	32.91	50.90	69.96	99.82
$\%\sigma_{TOA}$	2.26	2.65	2.96	2.79	2.41	2.22	1.88
$\%\sigma_{\overline{TOA}}$	.60	.71	.79	.75	.64	.59	.54
$\overline{TOA}/W^{1/3}$	5.41	12.37	24.56	37.20	57.54	79.09	112.84

(WEIGHT = .294 LB)

SHOT# \ λ	65.91	95.05	131.82	163.04	206.05	246.29	308.03
3049	6.00	13.39	26.75	39.85	60.04	81.28	113.20
3051	5.97	13.37	26.67	39.72	59.82	80.94	112.70
3056	5.98	13.32	26.16	38.75	58.51	79.44	111.03
3059	6.07	13.77	-	40.94	-	-	115.58
3064	6.13	13.94	27.93	41.56	62.42	84.10	116.63
3066	5.95	13.48	27.03	40.35	60.87	82.29	114.56
3076	5.81	13.06	25.67	38.50	58.66	78.80	111.16
3078	5.79	12.92	25.27	37.93	58.00	78.09	110.45
3081	5.79	12.95	25.27	37.94	57.98	78.07	110.42
$\overline{TOA}$	5.94	13.36	26.34	39.50	59.54	80.38	112.86
$\%\sigma_{TOA}$	2.07	2.61	3.53	3.31	2.62	2.68	2.05
$\%\sigma_{\overline{TOA}}$	.69	.87	1.25	1.10	.93	.95	.68
$\overline{TOA}/W^{1/3}$	8.23	18.45	36.55	54.57	82.61	111.53	156.60

1) TIME OF ARRIVAL DATA ARE IN MSEC
2) λ = SCALED DISTANCE (FT/LB$^{1/3}$)
3) $\overline{TOA}$ = MEAN TIME OF ARRIVAL (MSEC)
4) $\% \sigma_{TOA}$ = STANDARD DEVIATION IN %
5) $\% \sigma_{\overline{TOA}}$ = STANDARD ERROR IN %
6) $\overline{TOA}/W^{1/3}$ = SCALED TIME OF ARRIVAL (MSEC/LB$^{1/3}$)

TABLE 4B TIME OF ARRIVAL RESULTS

TIME OF ARRIVAL DATA FOR PENTOLITE (N_2 IN CST)

(WEIGHT = .692 LB)

λ / SHOT#	53.70	77.44	107.39	132.83	167.87	200.66	252.63
3095	-	9.76	-	29.99	47.44	65.92	97.79
3096	-	9.97	-	30.39	48.02	66.67	98.83
3097	-	10.12	-	30.76	48.33	66.94	99.02
3098	4.61	10.20	19.85	30.59	48.05	66.51	98.35
3099	4.63	10.29	19.96	30.84	48.40	66.90	98.79
3100	4.52	10.07	19.79	30.59	48.07	66.54	98.33
3101	4.53	10.12	20.15	31.02	48.92	67.81	-
3102	4.62	10.28	19.87	31.04	48.73	67.38	-
$\overline{TOA}$	4.58	10.10	19.92	30.65	48.24	66.83	98.52
$\%\sigma_{TOA}$	1.15	1.73	.70	1.14	.96	.86	.46
$\%\sigma_{\overline{TOA}}$	.51	.61	.31	.40	.34	.30	.19
$\overline{TOA}/W^{1/3}$	5.18	11.42	22.52	34.64	54.53	75.54	111.36

1) TIME OF ARRIVAL DATA ARE IN MSEC

2) λ = SCALED DISTANCE (FT/LB $^{1/3}$)

3) $\overline{TOA}$ = MEAN TIME OF ARRIVAL (MSEC)

4) $\%\sigma_{TOA}$ = STANDARD DEVIATION IN %

5) $\%\sigma_{\overline{TOA}}$ = STANDARD ERROR IN %

6) $\overline{TOA}/W^{1/3}$ = SCALED TIME OF ARRIVAL (MSEC/LB $^{1/3}$)

TABLE 4C TIME OF ARRIVAL RESULTS

TIME OF ARRIVAL DATA FOR TNETB
(WEIGHT = .303 LB)

SHOT# \ λ	70.74	102.01	141.47	174.98	221.15	264.33	330.60
3047	5.95	13.06	25.85	38.90	59.07	79.42	112.32
3052	6.02	13.45	26.45	39.53	59.67	79.91	112.73
3055	6.09	13.56	26.92	40.24	60.59	80.90	113.69
3060	6.34	14.36	28.55	42.63	63.80	84.80	118.27
3063	6.18	13.96	27.92	41.87	62.92	83.85	117.27
3068	6.17	13.84	27.52	41.19	61.87	82.57	115.61
3077	6.00	13.15	26.28	38.81	59.26	79.68	112.27
3079	5.98	13.13	26.26	39.75	59.21	79.61	112.15
3080	6.07	13.30	26.57	39.14	59.64	80.09	112.66
$\overline{TOA}$	6.09	13.53	26.92	40.22	60.67	81.20	114.11
$\%\sigma_{TOA}$	2.03	3.26	3.31	3.44	2.92	2.50	2.06
$\%\sigma_{\overline{TOA}}$	.68	1.09	1.10	1.15	.97	.83	.69
$\overline{TOA}/W^{1/3}$	9.07	20.15	40.09	59.91	90.35	120.92	169.93

(WEIGHT = .606 LB.)

SHOT# \ λ	56.13	80.95	112.27	138.86	175.49	209.77	262.35
3048	4.83	10.93	21.56	32.66	50.48	68.85	99.32
3050	4.87	10.97	21.62	32.69	50.43	68.66	98.94
3054	5.19	11.25	21.81	32.87	50.63	68.88	99.20
3061	5.09	11.82	23.67	35.66	54.21	72.87	103.50
3065	4.93	11.23	22.50	34.14	52.33	70.75	101.15
3067	4.89	11.16	22.30	33.71	51.53	69.71	99.76
3074	4.74	10.64	21.44	31.96	49.95	68.30	98.28
3075	4.92	10.99	22.05	32.71	50.80	69.27	99.39
$\overline{TOA}$	4.93	11.12	22.12	33.30	51.30	69.66	99.94
$\%\sigma_{TOA}$	2.91	3.09	3.29	3.51	2.71	2.15	1.66
$\%\sigma_{\overline{TOA}}$	1.03	1.09	1.16	1.24	.96	.76	.59
$\overline{TOA}/W^{1/3}$	5.83	13.14	26.14	39.35	60.62	82.32	118.10

1) TIME OF ARRIVAL DATA ARE IN MSEC.
2) λ = SCALED DISTANCE (FT/LB$^{1/3}$)
3) $\overline{TOA}$ = MEAN TIME OF ARRIVAL (MSEC)
4) $\%\sigma_{TOA}$ = STANDARD DEVIATION IN %
5) $\%\sigma_{\overline{TOA}}$ = STANDARD ERROR IN %
6) $\overline{TOA}/W^{1/3}$ = SCALED TIME OF ARRIVAL (MSEC/LB$^{1/3}$)

TABLE 5A PEAK PRESSURE RESULTS

PEAK PRESSURE DATA FOR TNT
(WEIGHT = .672 LB)

SHOT# \ λ	79.91	108.45	134.13	171.23	202.63
2001				19.5	
2004	121	56		19.5	
2007	121	57	33	19	13
2008	127	57	35	20	13
2080	108	54	36	19.5	13
2087	100	51	32.5	18.5	13
2088	100	51	32.5	18.5	13
2211	98	51.5	32.8	18.5	13.5
2221*	88	48	30.3	18	13
2224*	92	50.5	32.5	18.5	13
$\overline{P}$	110.7	53.9	33.6	19.1	13.1
% σ_P	10.91	5.15	4.44	3.05	1.56
% $\sigma_{\overline{P}}$	4.12	1.95	1.81	1.08	.64

PEAK PRESSURE DATA FOR H-6
(WEIGHT = .715 LB)

SHOT# \ λ	78.26	106.22	131.37	167.71	198.46
2002				27.5	
2003	153	75	46	27.0	
2005	155	75	48	27.5	
2009	162	80	45	27.5	20
2010	151	72	45	27.5	19.5
2081	142	75	48	26.5	19.5
2086	130	66	45	25.5	18.5
2091	135	70.5	46.5	25.5	19
2209	131	71	45.5	26	20.5
2218*	112	65	44.5	24.5	17.5
$\overline{P}$	144.8	73.1	46.1	26.7	19.5
% σ_P	8.33	5.70	2.76	3.26	3.63
% $\sigma_{\overline{P}}$	2.94	2.01	.98	1.09	1.48

(WEIGHT = .362 LB)

SHOT# \ λ	98.20	133.28	164.84	210.44	249.02
2069*	89	45.5	26.5	14.5	11
2070*	85	43	23	14.5	11
2074	69	37	21.5	13.5	9
2075	70	37	21	13.5	10
2079	69	37	21.5	13.5	9
2083	63.5	34	20	12.5	9
2085	62	32.5	20	12.5	9
2090	63.5	34.5	20	13	9
2210	62	33.5	20.5	12.5	9.3
2214	57	33.5	20.5	12	8.7
2220*	52	31	20.5	11.5	9
2227*	53	29	19	11	
$\overline{P}$	64.5	34.9	20.6	12.9	9.1
% σ_P	6.97	5.30	3.11	4.52	4.25
% $\sigma_{\overline{P}}$	2.46	1.87	1.10	1.60	1.50

(WEIGHT = .380 LB)

SHOT# \ λ	96.61	131.11	162.16	207.01	244.96
2071*	98	48.5	29.5	18.5	13
2072*	95	49.5	29.5	18.5	
2076	93	47.5	29	18.0	13
2077	93	47.5	29	17.5	12.5
2078	92	47	29	17.0	12.5
2089	85.5	43.5	27.5	16.5	12
2213		44.5	26.5	16.5	12.5
2222*	74	38.5	24	15	11
2226*	73	37.5	23	15	10.5
$\overline{P}$	90.9	46.0	28.2	17.1	12.5
% σ_P	3.98	4.07	4.08	3.81	2.83
% $\sigma_{\overline{P}}$	1.99	1.82	1.83	1.70	1.26

1) ALL PRESSURES ARE IN PSI
2) λ = SCALED DISTANCE (FT/LB$^{1/3}$)
3) $\overline{P}$ = MEAN PEAK PRESSURE (PSI)
4) % σ_P = STANDARD DEVIATION IN %
5) % $\sigma_{\overline{P}}$ = STANDARD ERROR IN %
6) ASTERISK (*) INDICATES DATA NOT INCLUDED IN ANALYSIS BECAUSE OF INSTRUMENTATION DIFFICULTIES.

TABLE 5B PEAK PRESSURE RESULTS

PEAK PRESSURE DATA FOR PENTOLITE
(WEIGHT = .692 LB)

SHOT# \ λ	53.70	79.14	107.41	132.84	169.59	200.68
2006		146	67	40.5	23	15.5
2008			57.5	38	20.7	16
2012		110	59	38	20.5	16
2016		115	61	39.5	21	16.5
2219*		100	53	35.5	19.25	14
2225*		102	53	34.5	19.5	14
2228*		96	55	34.5	19	14.5
2230	220		57	34.5	19.5	
2231			58.3			
2232	223		58.5	35.5	19.5	15
2233			58	31.5	19.3	13.5
2234			57	31	19	13.5
3044		98				
3045		106				
3046		103	49.2			
3053		101.5	56.5		19.8	14.6
3057		103	56.5		21	15.1
3058		98	53.8		18.2	14
3062			49.2			
3069*		84	48		19.8	15.1
3070*		81	48		19.1	14
3071*		81	50		19.1	14
3072*		89	50			14
3073*		89				
3093	218		50			
3094	250		67			
$\overline{P}$	227.8	108.9	57.3	36.1	20.1	15.0
% σ_P	6.58	13.71	9.54	9.84	6.44	7.10
% $\sigma_{\overline{P}}$	3.29	4.57	2.38	3.48	1.94	2.24

PEAK PRESSURE DATA FOR PENTOLITE (CONT'D)
(WEIGHT = .374 LB)

SHOT# \ λ	105.29	142.90	176.74	225.63	266.70
2073	69	36	21	13.5	9
2082	60	32.8	19	12	9
2084	56.5	29.5	18.5	12	8.5
$\overline{P}$	61.8	32.8	19.5	12.5	8.8
% σ_P	10.43	9.92	6.78	6.93	3.27
% $\sigma_{\overline{P}}$	6.02	5.73	3.92	4.00	1.89

(WEIGHT = .294 LB)

SHOT# \ λ	97.15	131.85	163.08	206.11	246.36
3049	53	28.2	17	12.3	9.8
3051	56	27.5	16.6	12.4	10.2
3056	60	34	17.9	13.1	10.9
3059	53	26.5	15	11.4	8.9
3064*	48	23.2	14.2	10.3	8.7
3066	54	24.4	15.5	—	—
3076	60	33	18.5	13.6	9.7
3078	68	36	18.9	13.1	10.5
3081	70	34.5	18.6	13.1	10.0
$\overline{P}$	59.3	30.5	17.3	12.7	10.0
% σ_P	11.22	14.25	8.53	5.77	6.38
% $\sigma_{\overline{P}}$	3.97	5.04	3.01	2.18	2.41

1) ALL PRESSURES ARE IN PSI
2) λ = SCALED DISTANCE (FT/LB $^{1/3}$)
3) $\overline{P}$ = MEAN PEAK PRESSURE (PSI)
4) % σ_P STANDARD DEVIATION IN %
5) % $\sigma_{\overline{P}}$ = STANDARD ERROR IN %
6) ASTERISK (*) INDICATES DATA NOT INCLUDED IN ANALYSIS BECAUSE OF INSTRUMENTATION DIFFICULTIES.

TABLE 5C PEAK PRESSURE RESULTS

PEAK PRESSURE DATA FOR PENTOLITE (N_2 IN CST)

(WEIGHT = .692 LB)

SHOT# \ λ	53.70	77.44	107.39	132.83	167.87	200.66	252.63
3095		132	60	27.1	18.2	11.3	7.8
3096		122		27.1	18.0	11.3	7.8
3097		120		26.8	18.2	11.3	7.8
3098	225	120	67	26.8	18.2	11.3	7.8
3099	230	120	66	25.5	18.2	11.3	7.8
3100	225	120	66	26.8	18.9	11.3	7.8
3101	218	115	59	25.5	16.5	10.7	
3102	230	115	59	25.5	17.4	11.3	
$\overline{P}$	225.6	120.5	62.8	26.4	18.0	11.2	7.8
% σ_P	2.19	4.39	6.16	2.82	3.97	1.89	0
% $\sigma_{\overline{P}}$	.98	1.55	2.51	1.00	1.40	.67	0

PEAK PRESSURE DATA FOR TNETB

(WEIGHT = .606 LB)

SHOT# \ λ	82.70	112.27	138.86	175.49	209.77
3048	94	50.2	27.9	16	9.9
3050	93.5	53.8	29.5	14	9.0
3054	94	50.2	28	18.9	14.6
3061*	74.5	38.5	23.5	17.2	14.0
3065*	81	40	25.5	18.2	14.0
3067*		46.5	26.5		14.7
3074	90.5	51	28	19.1	15.1
3075	86.5	50	28	18.9	14.0
$\overline{P}$	91.7	51.0	28.3	17.4	12.5
% σ_P	3.55	3.12	2.42	13.15	22.74
% $\sigma_{\overline{P}}$	1.59	1.39	1.08	5.88	10.17

(WEIGHT = .303 LB)

SHOT# \ λ	104.24	141.47	174.98	221.15	264.3
3047	60	32.3	17.5	12.3	9.6
3052	56	32.0	17	13.1	10.2
3055	53	27	16.1	12.0	9.6
3060*	44.5	20.5	13.7	10.2	8.4
3063*	48	20.8	13.7	10.2	8.7
3068*	48	22.5	14.7	11.4	9.2
3077	54.5	31.2	17.5	12.3	9.8
3079	54.5	35	17.6	12.3	9.6
3080	56.0	32.5	17.5	12.3	9.6
$\overline{P}$	55.6	31.7	17.2	12.4	9.7
% σ_P	4.35	8.26	3.37	3.00	2.49
% $\sigma_{\overline{P}}$	1.78	3.37	1.38	1.22	1.02

1) ALL PRESSURES ARE IN PSI
2) λ = SCALED DISTANCE (FT/LB $^{1/3}$)
3) $\overline{P}$ = MEAN PEAK PRESSURE (PSI)
4) $\%\sigma_P$ = STANDARD DEVIATION IN %
5) $\%\sigma_{\overline{P}}$ = STANDARD ERROR IN %
6) ASTERISK (*) INDICATES DATA NOT INCLUDED IN ANALYSIS BECAUSE OF INSTRUMENTATION DIFFICULTIES.

TABLE 6A POSITIVE IMPULSE RESULTS

POSITIVE IMPULSE DATA FOR TNT
(WEIGHT = .672 LB)

SHOT# \ λ	79.91	108.45	134.13	171.23	202.63
2004	1581	529	-	315	-
2007	2066	682	635	708	375
2008	1943	770	468	719	464
2080	961	450	433	324	250
2087	639	325	234	218	339
2088	767	471	323	284	339
2211	1022	525	253	244	270
$\bar{I}$	1283	536	391	402	340
$\%\sigma_I$	44.9	27.7	38.9	53.8	22.7
$\%\sigma_{\bar{I}}$	17.0	10.5	15.9	20.3	9.3

(WEIGHT = .362 LB)

SHOT# \ λ	98.20	133.28	164.84	210.44	249.02
2074	662	385	258	239	264
2075	569	355	246	239	278
2079	662	386	258	227	186
2083	-	-	-	-	-
2085	356	261	229*	205	199
2090	693	624*	399*	284*	206
2210	274	316	257	206	205
2214	792	416	249	209	204
$\bar{I}$	573	353	254	221	220
$\%\sigma_I$	33.0	16.0	2.2	7.3	16.1
$\%\sigma_{\bar{I}}$	12.5	6.5	1.0	3.0	6.1

POSITIVE IMPULSE DATA FOR H-6
(WEIGHT .715 LB)

SHOT# \ λ	78.26	106.62	131.37	167.71	198.46
2002	-	-	-	-	-
2003	1674	570	479	436	-
2005	1415	616	445	394	-
2009	2914	963	881	930	892
2010	2801	1244*	881	930	641
2081	1833	769	534	463	339
2086	976	537	507	413	272
2091	1032	622	452	414	330
2209	1575	768	660	397	640*
$\bar{I}$	1778	692	605	547	519
$\%\sigma_I$	41.0	21.7	30.3	43.4	47.0
$\%\sigma_{\bar{I}}$	14.5	8.2	10.7	15.3	19.2

(WEIGHT = .380 LB)

SHOT# \ λ	96.61	131.11	162.16	207.01	244.96
2076	812	537	302	289	271*
2077	983	559	336	299	204
2078	873	513	302	286	204
2089	693	624	399*	284	205
2213	450	461	323	279	213
$\bar{I}$	762	539	316	287	206
$\%\sigma_I$	26.7	11.1	5.3	2.6	2.1
$\%\sigma_{\bar{I}}$	12.0	5.0	2.7	1.2	1.1

1) ALL POSTIVE IMPULSES ARE IN PSI-MSEC
2) λ = SCALED DISTANCE $(FT/LB^{1/3})$
3) $\bar{I}$ = MEAN POSTIVE IMPLUSE (PSI-MSEC)
4) $\%\sigma_I$ = STANDARD DEVATION IN %
5) $\%\sigma_{\bar{I}}$ = STANDARD ERROR IN %
6) * = DATA REJECTED BY CHAUVANET'S CRITERION

TABLE 6B POSITIVE IMPULSE RESULTS

POSITIVE IMPULSE DATA FOR PENTOLITE
(WEIGHT = .692 LB)

SHOT# \ λ	107.41	132.84	169.59	200.68
2208	470	377 *	355 *	429
2212	612	566 *	310 *	429
2216	512	329	243	355
2230	129	277	245	-
2231	116	-	-	-
2232	163	274	256	307
2233	-	274	256	278
2234	122	269	220	272
3044	-	-	-	-
3045	-	-	-	-
3046	452	301	-	-
3053	337	320	277	170
3057	337	214 *	204	127
3058	340	253	197	127
3062	467	298	194	129
3093	437	268	228	193
3094	436	291	229	199
$\bar{I}$	352	287	232	251
$\% \sigma_I$	45.9	8.2	11.5	44.4
$\% \sigma_{\bar{I}}$	12.3	2.5	3.5	12.8

(WEIGHT = .294 LB)

SHOT# \ λ	131.85	163.08	206.11	246.36
3049	231	218	208	157
3051	290	227	188	136
3056	235	188	185	183
3059	236	223	206	162
3066	239	177	-	-
3076	313	219	206	122
3078	315	184	144	114
3081	314	184	165	134
$\bar{I}$	272	202	186	144
$\% \sigma_I$	14.6	10.4	13.0	17.0
$\% \sigma_{\bar{I}}$	5.2	3.7	4.9	5.5

1) ALL POSTIVE IMPULSES ARE IN PSI-MSEC
2) λ = SCALED DISTANCE (FT/LB$^{1/3}$)
3) $\bar{I}$ = MEAN POSTIVE IMPLUSE (PSI-MSEC)
4) $\% \sigma_I$ = STANDARD DEVATION IN %
5) $\% \sigma_{\bar{I}}$ = STANDARD ERROR IN %
6) * = DATA REJECTED BY CHAUVANET'S CRITERION

TABLE 6C POSITIVE IMPULSE RESULTS

POSITIVE IMPULSE DATA FOR PENTOLITE (N_2)

(WEIGHT .692 LB)

SHOT# \ λ	77.43	107.38	132.81	167.85	200.63
3095	577	531	270	245	193
3096	576	-	270	243	193
3097	532	-	268	245	193
3098	532	538	269	245	193
3099	533	535	278	245	193
3100	532	535	268	217	193
3101	518	431	270	228	199
3102	518	431	278	218	193
$\bar{I}$	540	500	271	236	194
$\%\sigma_I$	4.4	10.7	1.5	5.4	1.1
$\%\sigma_{\bar{I}}$	1.5	4.4	.54	1.9	.39

POSITIVE IMPULSE DATA FOR TNETB

(WEIGHT = .303 LB)

SHOT# \ λ	141.47	174.98	221.15	264.3
3047	233	155	166	114
3052	231	218	185	136
3055	351	240	144	114
3060	173	158	146	143
3063	233	201	188	141
3068	235	178	165	139
3077	236	187	145	112
3079	312	184	163	136
3080	262	187	163	114
$\bar{I}$	252	190	163	128
$\%\sigma_I$	20.6	14.3	9.9	10.7
$\%\sigma_{\bar{I}}$	6.9	4.8	3.3	3.6

(WEIGHT = .606 LB)

SHOT# \ λ	112.27	138.86	175.49	209.77
3048	326	291	262	115 *
3050	340	337 *	257	183
3054	326	297	239	213 *
3061	467 *	297	237	177
3065	350	294	236	170
3067	352	269	243	178
3074	407 *	266	235	168
3075	-	-	-	-
$\bar{I}$	339	286	244	175
$\%\sigma_I$	3.7	5.0	4.5	3.5
$\%\sigma_{\bar{I}}$	1.7	2.0	1.7	1.6

1) ALL POSTIVE IMPULSES ARE IN PSI-MSEC
2) λ = SCALED DISTANCE (FT/LB$^{1/3}$)
3) $\bar{I}$ = MEAN POSTIVE IMPLUSE (PSI-MSEC)
4) $\%\sigma_I$ = STANDARD DEVATION IN %
5) $\%\sigma_{\bar{I}}$ = STANDARD ERROR IN %
6) * = DATA REJECTED BY CHAUVANET'S CRITERION

TABLE 7 COEFFICIENTS OF THE FITS FOR PRESSURE AND TIME-OF-ARRIVAL DATA (EQUATIONS 3,4)

EXPLOSIVE	A	B	a_0	a_1	a_2	a_3
TNT	1.625×10^6	-2.201				
H - 6	1.785×10^6	-2.165				
TNETB	0.689×10^6	-2.030	-3.442	3.118×10^{-2}	2.330×10^{-3}	-2.542×10^{-6}
PENTOLITE	0.881×10^6	-2.075	-2.219	3.013×10^{-3}	2.621×10^{-3}	-3.114×10^{-6}
PENTOLITE *	0.901×10^6	-2.070	-	-	-	-
PENTOLITE (N_2)	2.283×10^6	-2.289	2.361	-1.055×10^{-2}	3.182×10^{-3}	-4.183×10^{-6}

* EXCLUDING 0.374 LB DATA

TABLE 8 AVERAGE EQUIVALENT WEIGHT RESULTS

EXPLOSIVE	FREE AIR		CONCIAL SHOCK TUBE			
	EW*	PRESSURE RANGE	EW*	PRESSURE RANGE	EW*	PRESSURE RANGE
H-6	1.27[1]	6-26	1.45	10-100	1.48	10-25
PENTOLITE	} 1.17[2]	3-23	0.98	10-100	1.07	10-25
PENTOLITE***			1.05	10-100	1.15	10-25
TNETB	1.13[2]	3-23	0.94	10-100	1.05	10-25
TNT	1.00		1.00	10-100	1.00	
PENTOLITE (N_2)	0.83[2]	5-30	0.90	10-100	0.82	5-30

* BASED UPON PEAK PRESSURE

*** EXCLUDING 0.374 LB DATA

1 REFERENCE 5

2 REFERENCE 3

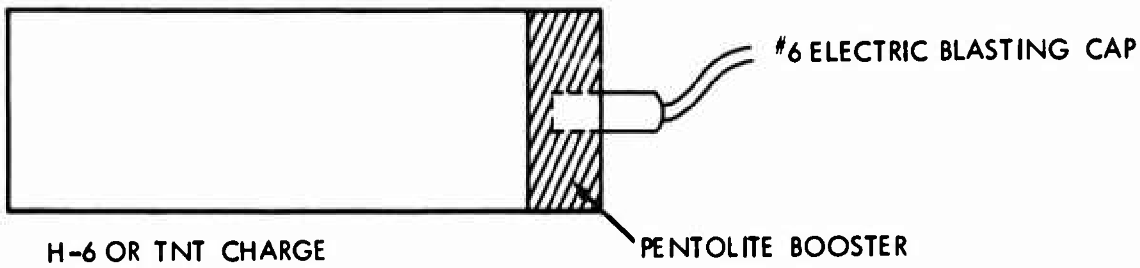
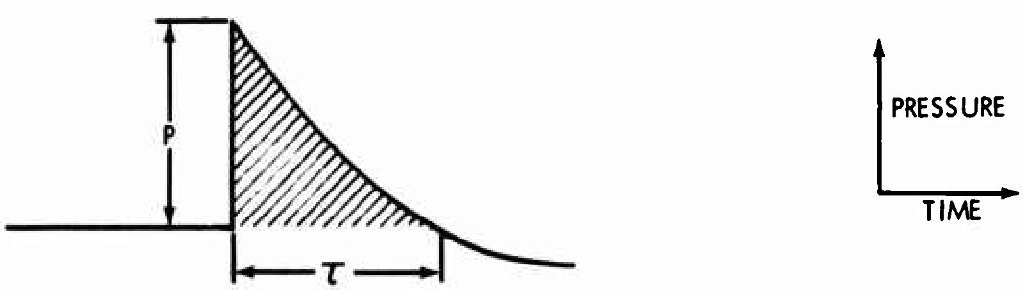


FIG. 1 CHARGE/BOOSTER CONFIGURATION



CROSS-HATCHED AREA REPRESENTS POSITIVE IMPULSE

FIG. 2 PRESSURE-TIME CURVE SHOWING VARIABLES OF INTEREST

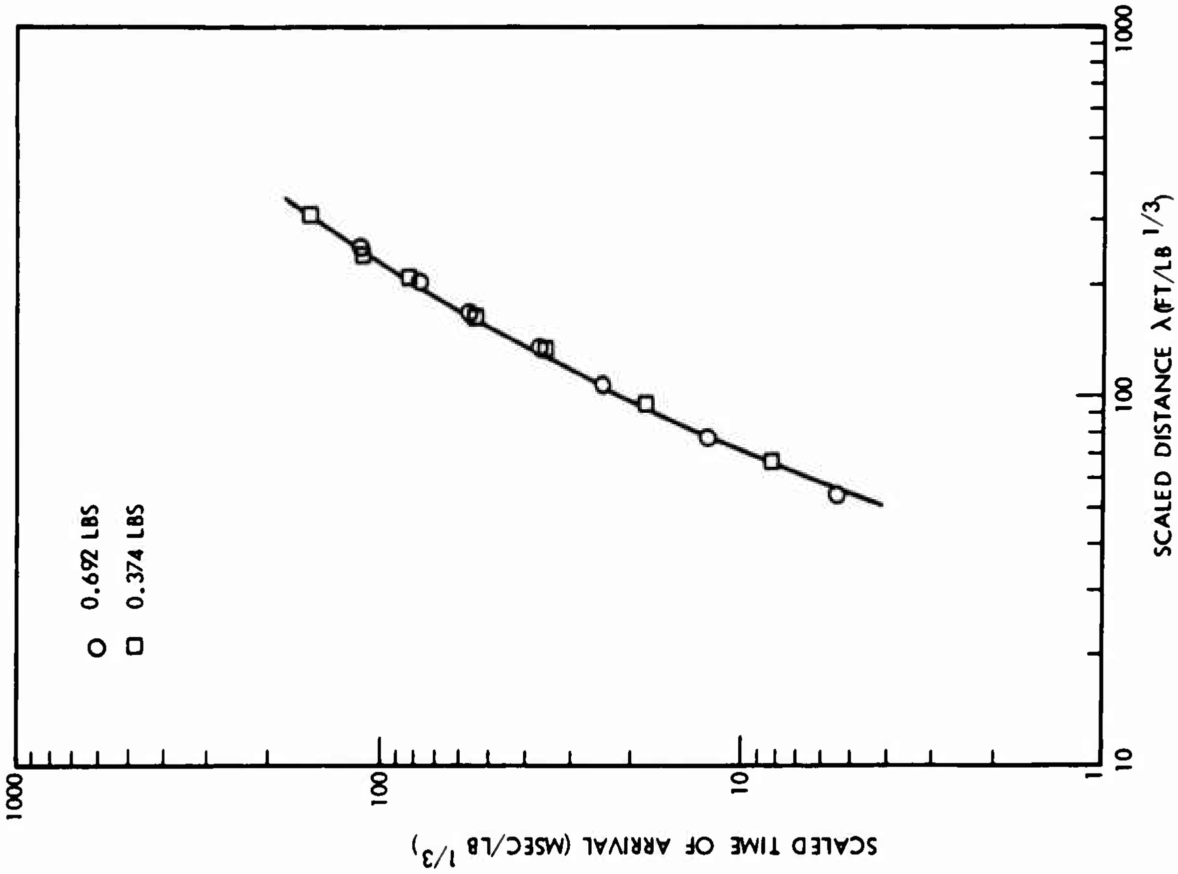


FIG. 3 SCALED TIME OF ARRIVAL VS SCALED DISTANCE FOR PENTOLITE

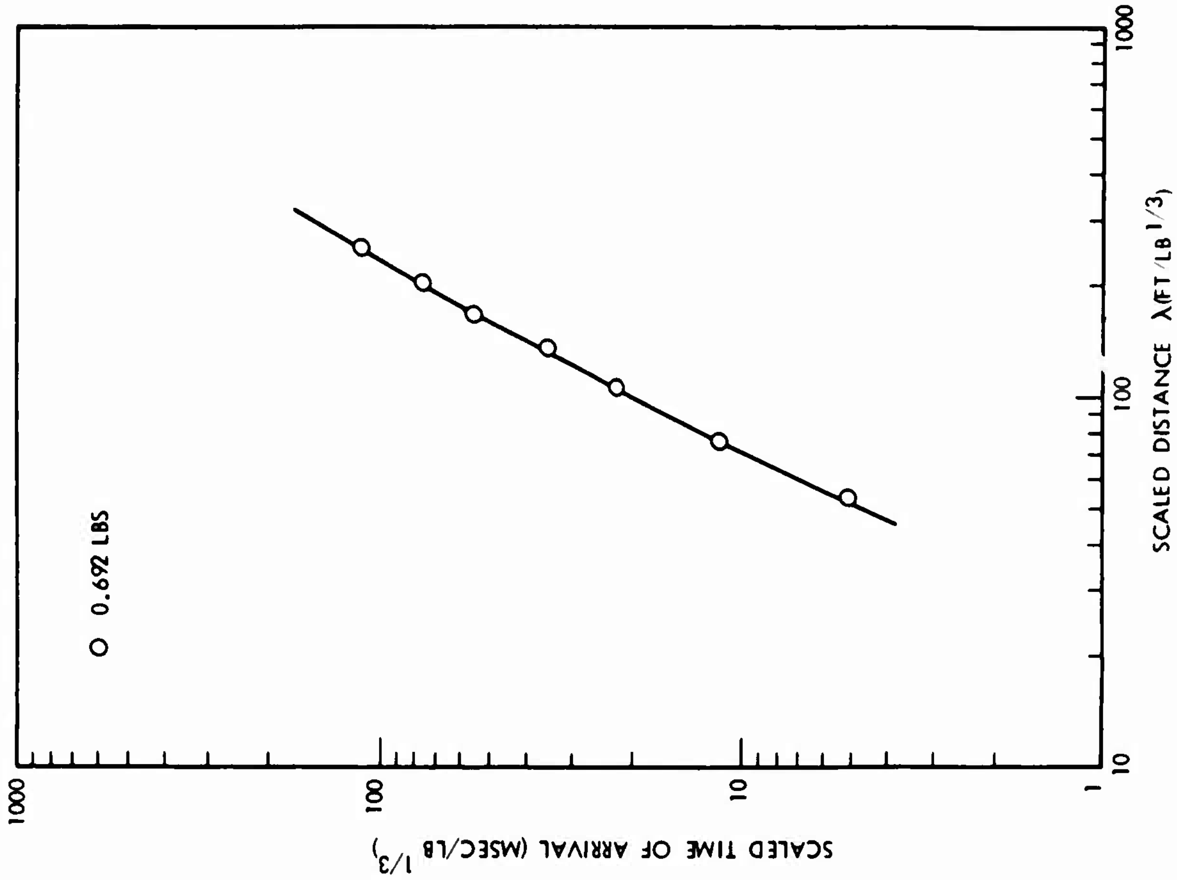


FIG. 4 SCALED TIME OF ARRIVAL VS SCALED DISTANCE FOR PENTOLITE (N_2)

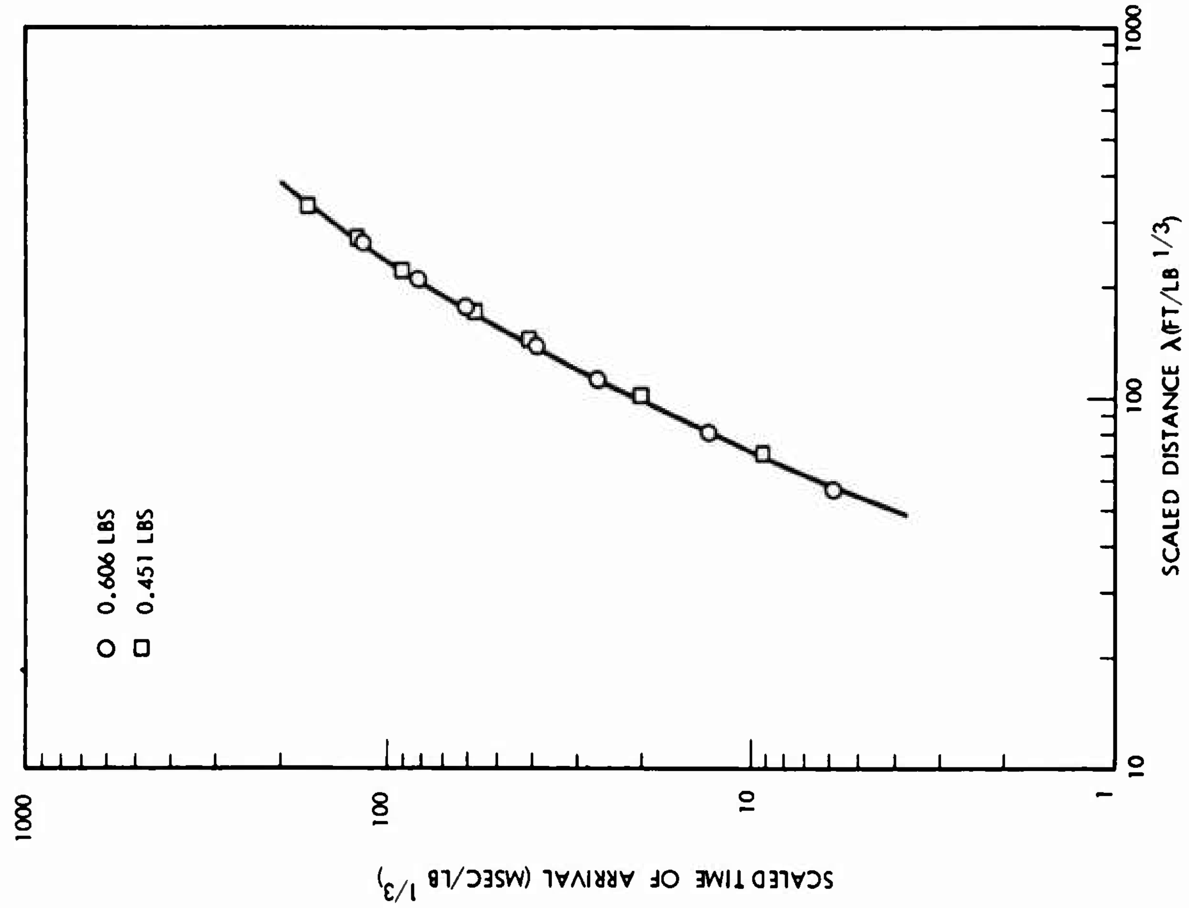


FIG. 5 SCALED TIME OF ARRIVAL VS SCALED DISTANCE FOR TNETB

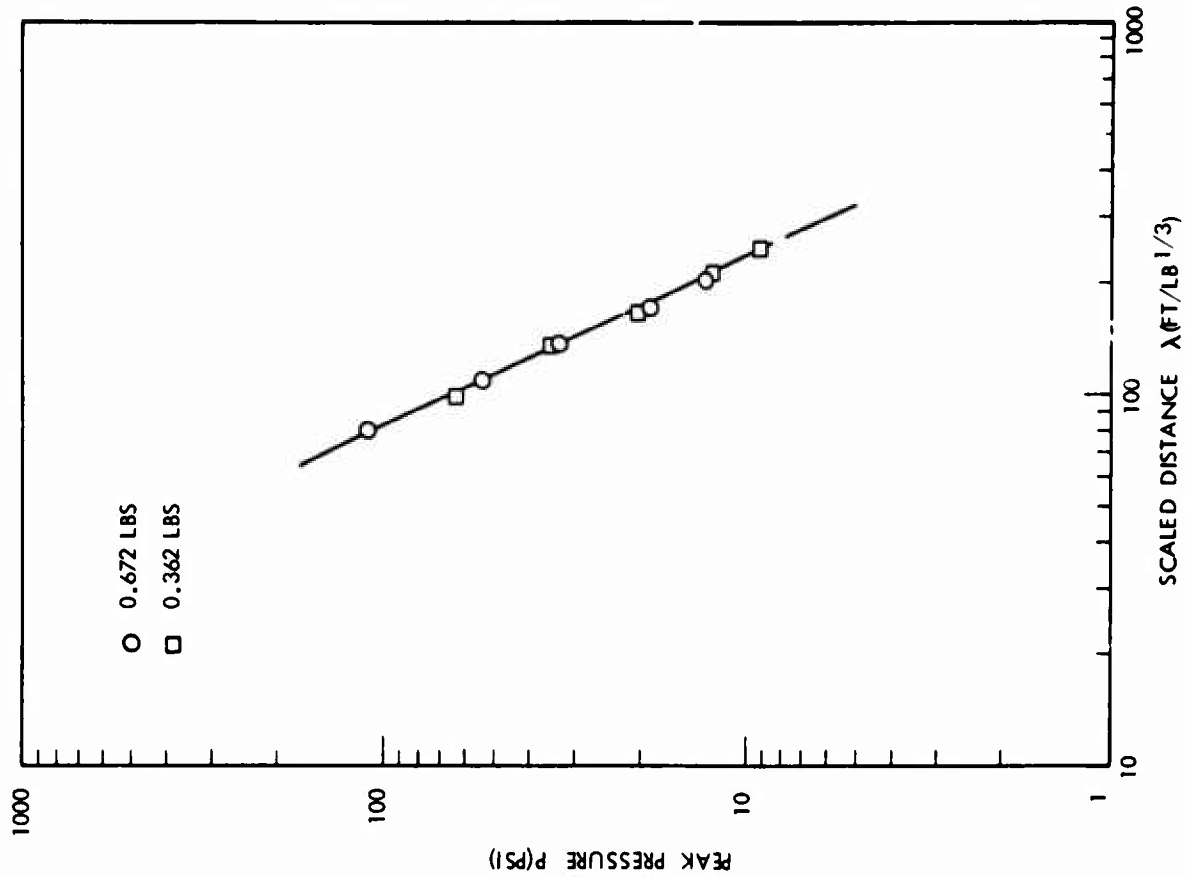


FIG. 6 PEAK PRESSURE VS SCALED DISTANCE FOR TNT

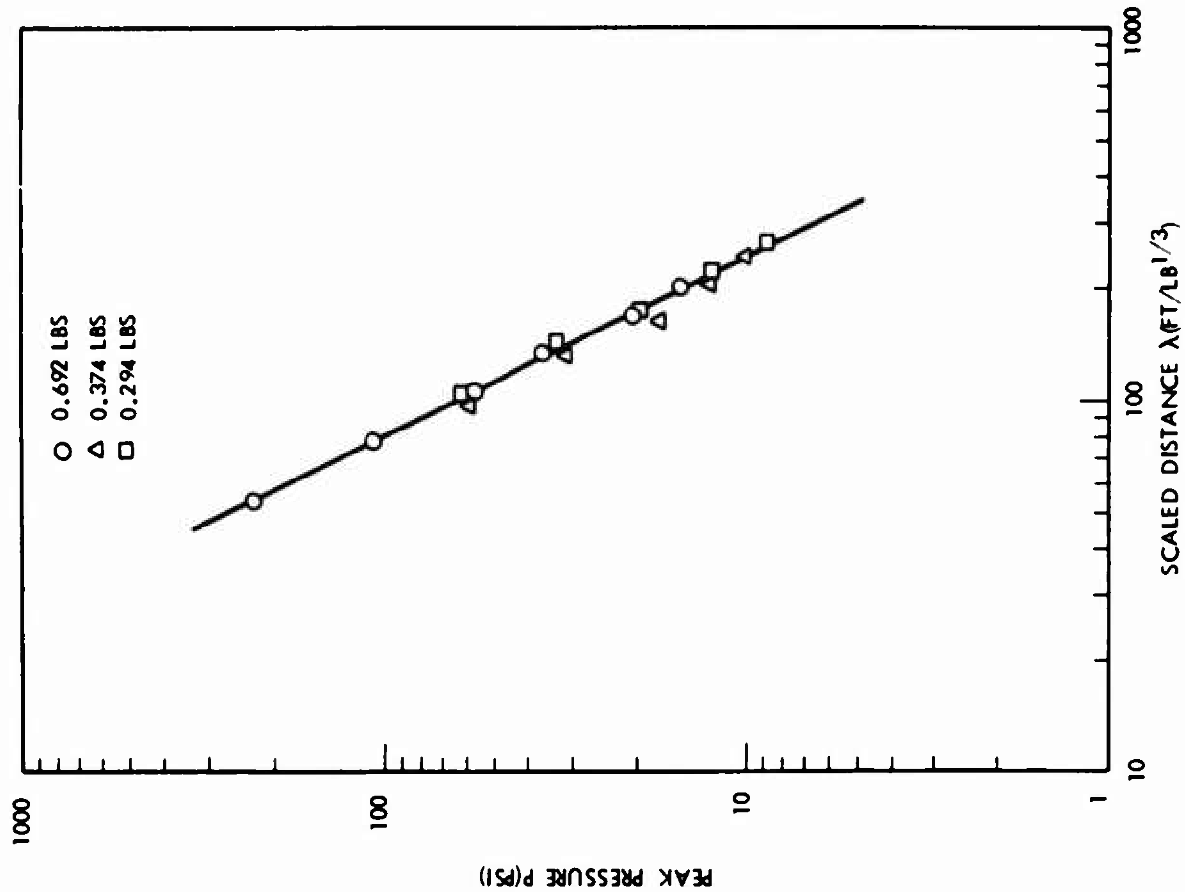


FIG. 8 PEAK PRESSURE VS SCALED DISTANCE FOR PENTOLITE

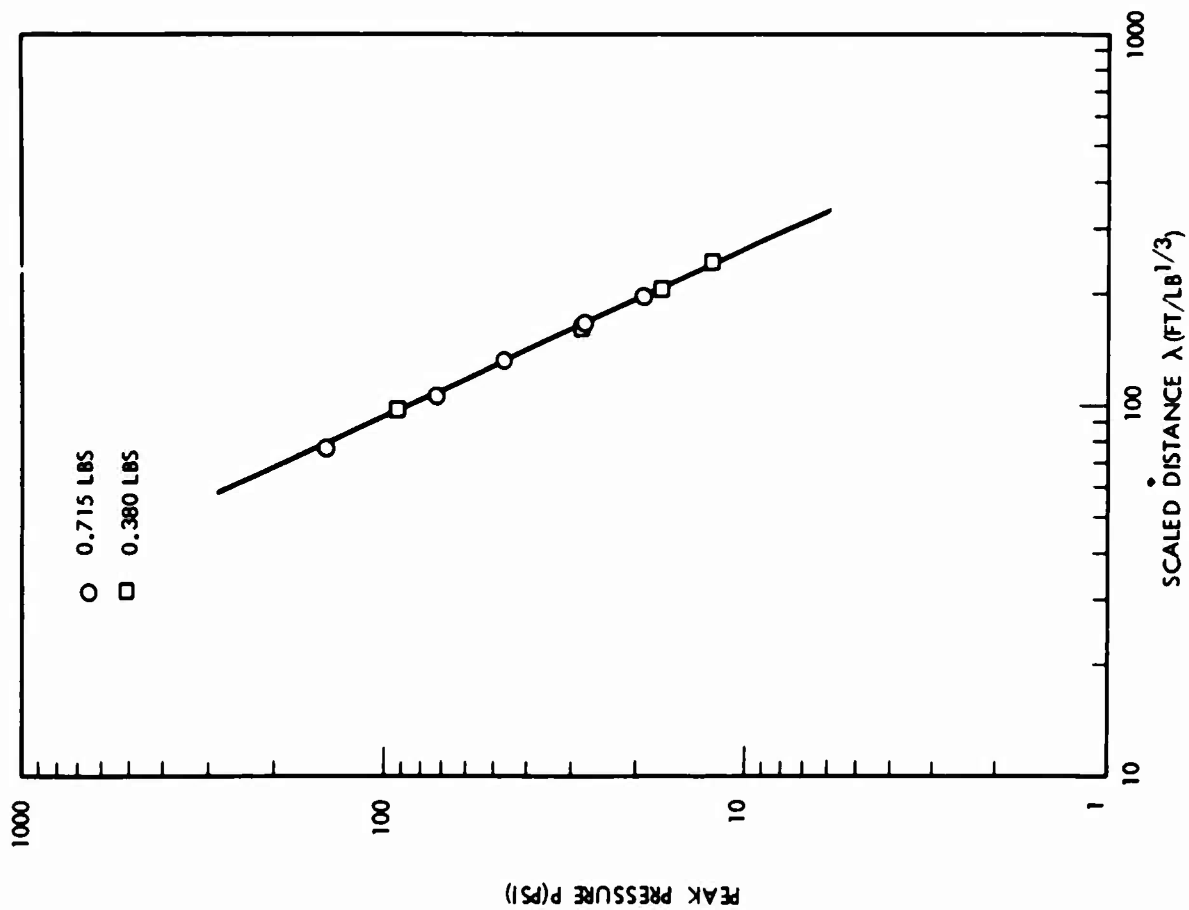


FIG. 7 PEAK PRESSURE VS SCALED DISTANCE FOR H-6

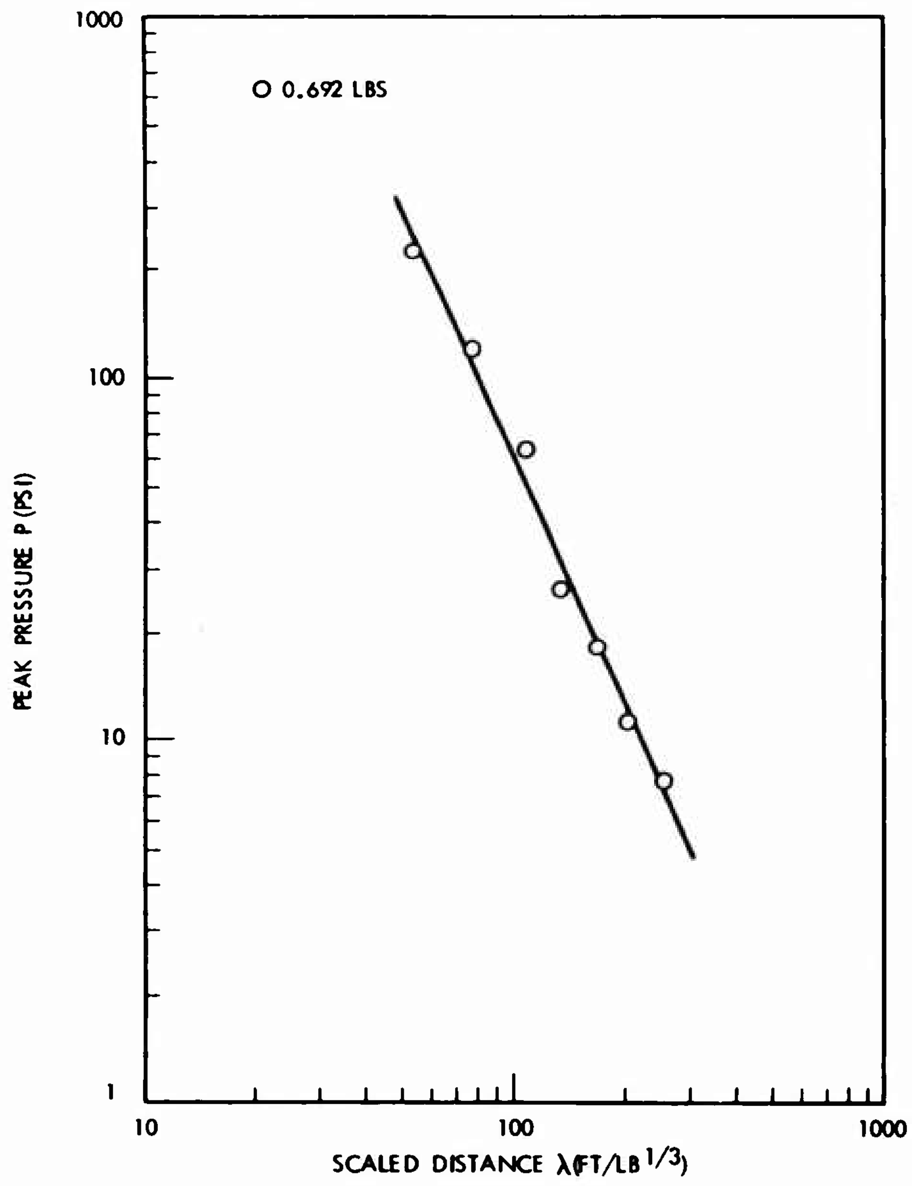


FIG. 9 PEAK PRESSURE VS SCALED DISTANCE FOR PENTOLITE (N_2)

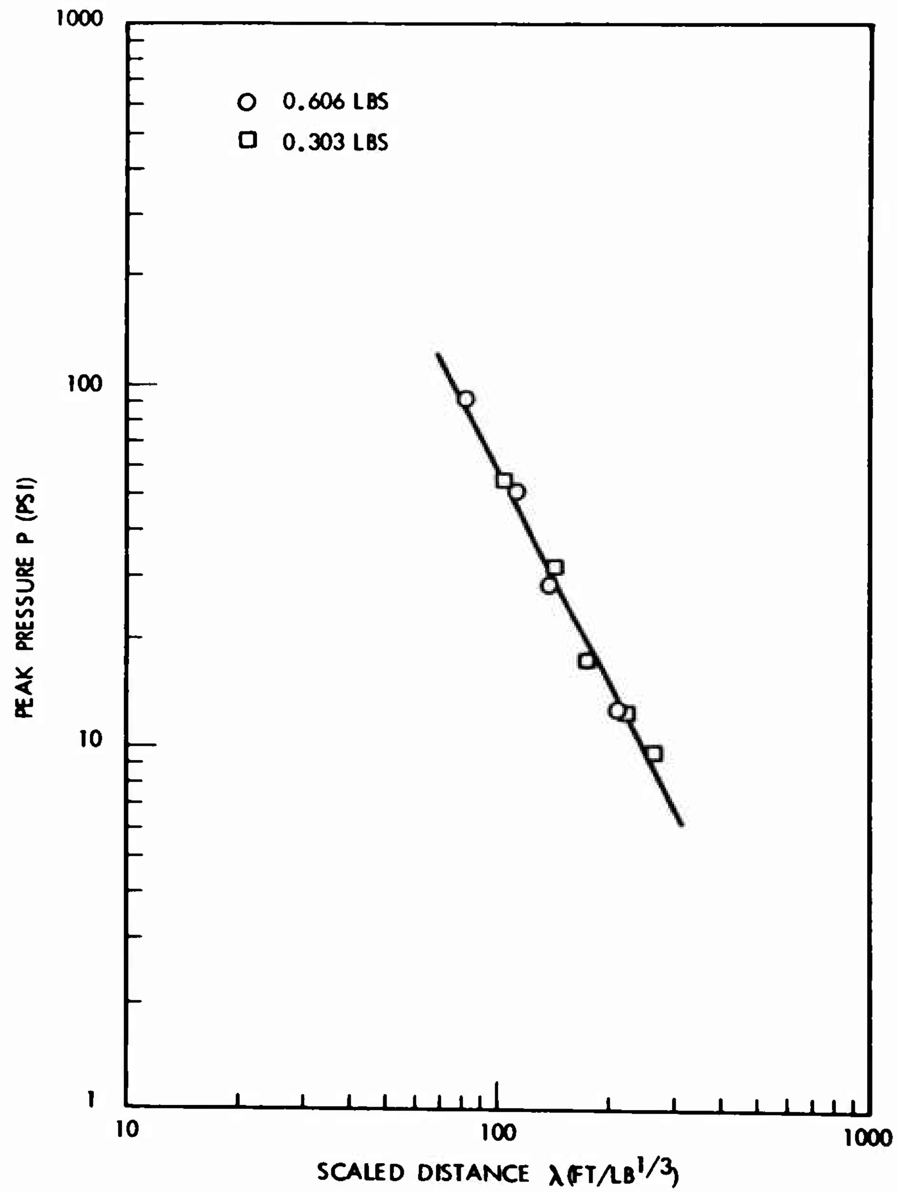


FIG. 10 PEAK PRESSURE VS SCALED DISTANCE FOR TNETB

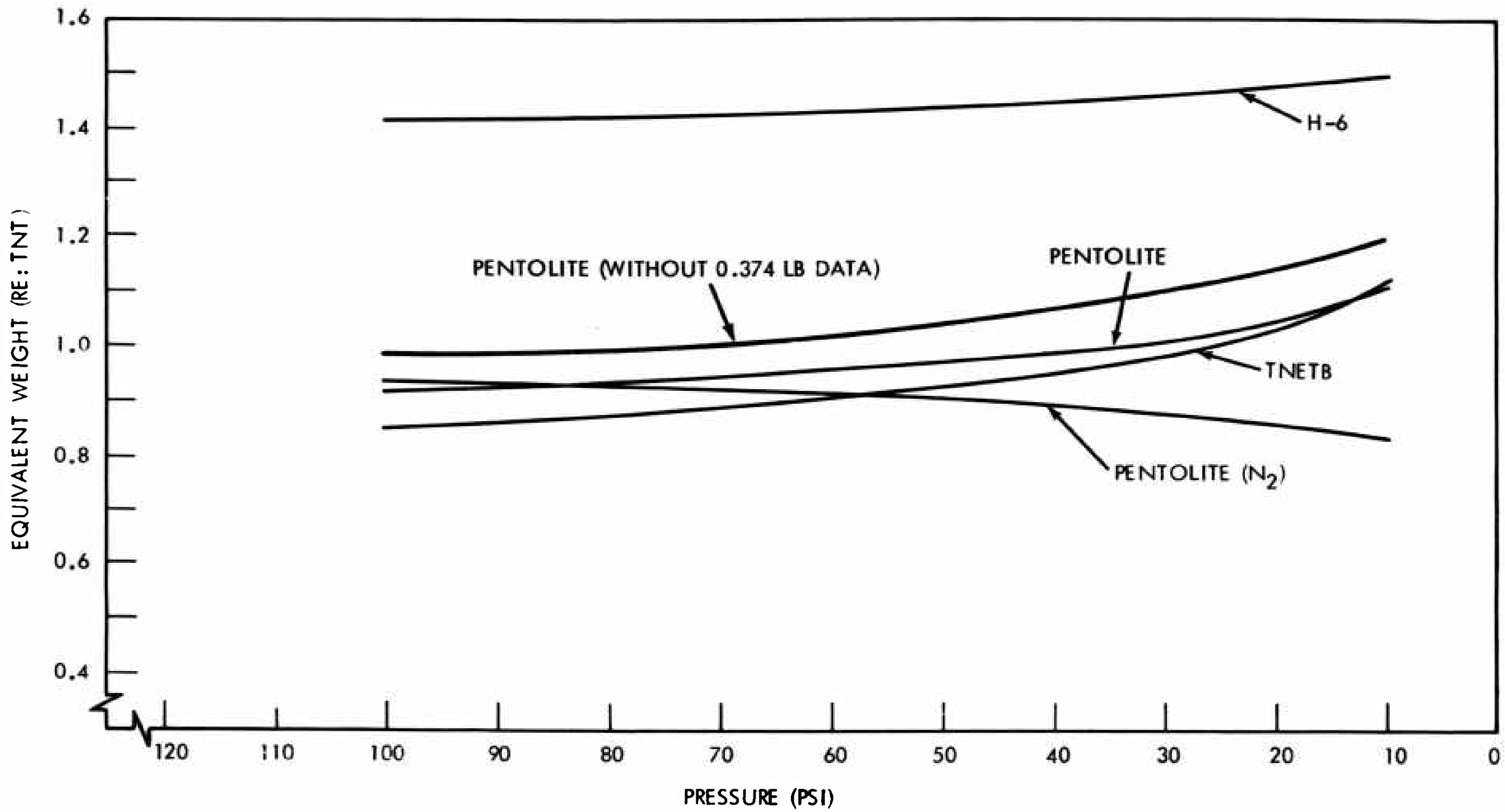


FIG. 11 THE VARIATION OF EQUIVALENT WEIGHT (RELATIVE TO TNT) WITH PRESSURE.

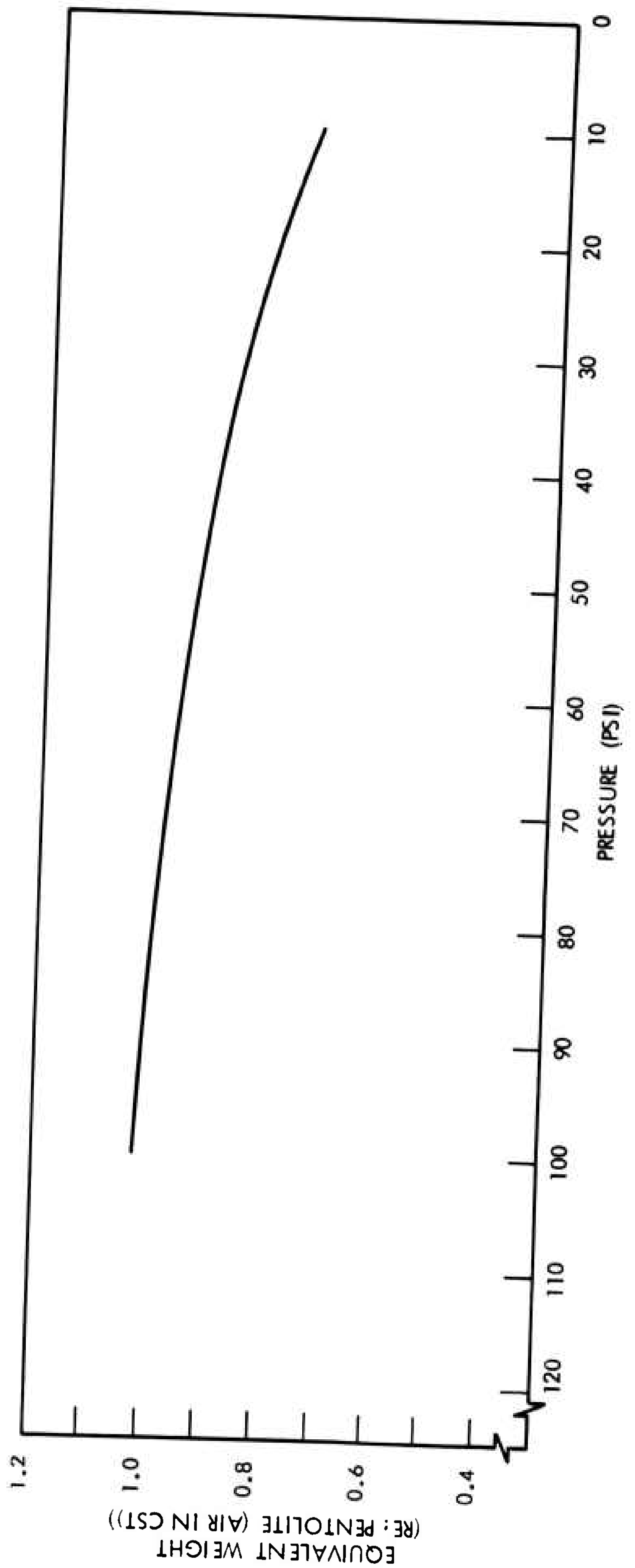
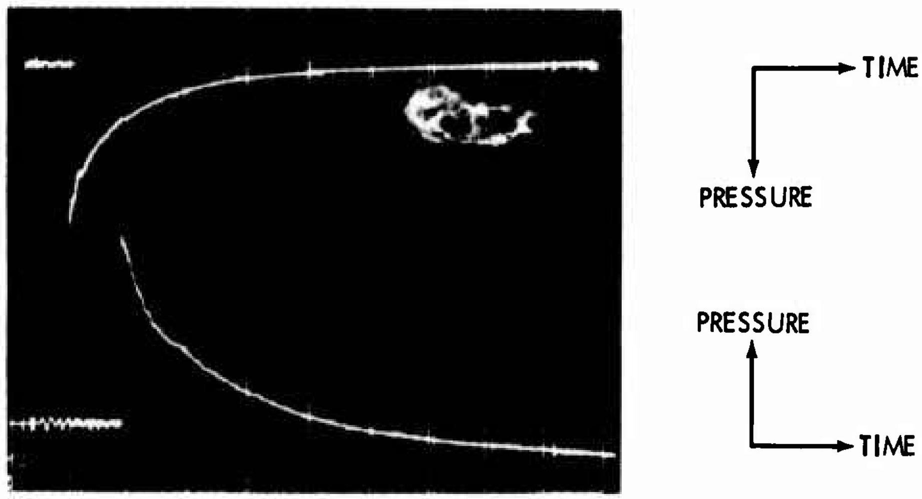


FIG. 12 THE EFFECTS OF A NITROGEN ATMOSPHERE ON THE EQUIVALENT WEIGHT OF PENTOLITE IN THE CST.



EXPLOSIVE - PENTOLITE
EXPLOSIVE WEIGHT - 0.692 POUNDS
SWEEP - 10 MSEC/MAJOR DIVISION

UPPER TRACE $\begin{cases} \text{LOCATION} = 70 \text{ FT} \\ P_{MAX} = 115 \text{ PSI} \end{cases}$

LOWER TRACE $\begin{cases} \text{LOCATION} = 95 \text{ FT} \\ P_{MAX} = 61 \text{ PSI} \end{cases}$

FIG. 13 REPRESENTATIVE PRESSURE-TIME RECORDS

UNCLASSIFIED

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13 ABSTRACT

Experiments were performed to determine whether or not the 180-foot conical shock tube facility located at the Naval Ordnance Laboratory can be used to determine free-air equivalent weights for several test explosives. The explosives tested were H-6, TNT, pentolite, and TNETB.

The rankings of explosives as determined in the CST agree with the rankings in free air.

Numerical values of equivalent weights vary with pressure, but even so the values obtained in the CST do not reproduce the single number usually cited for equivalent weights determined in free air using conventional methods. The variations are believed to be real and presently are thought as likely to represent an uncertainty in the conventional concept of equivalent weight just as much as a fundamental limitation of the conical shock tube. Analysis continues to resolve these differences.

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14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
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